DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

Chapter 5

Wheat Fertilization and Liming Practices

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A sound soil fertility program is essential for profitable wheat production. University of Arkansas Cooperative Extension Service Crop Enterprise Budget estimates indicate that fertilization and liming account for as much as 45% of the total input costs associated with wheat production in Arkansas. In order to maximize yields and produce wheat profitably, producers must ensure that adequate amounts of essential plant nutrients are available when needed by the crop. Although fertilization and liming practices are just one portion of producing a profitable wheat crop, the soil and fertilizer nutrients will not be used efficiently if producers do not take the time to identify other yield-limiting factors such as poor soil drainage and ryegrass infestations. The objectives of this chapter are to (1) review soil-based fertilizer and lime recommendations, (2) review nutrient deficiencies commonly seen in Arkansas wheat and (3) provide research- and/or experience-based insight on effective nutrient management practices.

Soil Testing

The best way to determine fertilizer and lime needs is with a soil test. Fertilizer and lime needs should be made based on the most recent soil test results, the field's history of soil test results and an examination of the field's crop yield and fertilization history. The most recent soil test will provide valuable information concerning the field's current status of available nutrients and pH suitability for producing wheat and other crops such as soybeans grown in the rotation. The history of soil test results will provide an indication of how consistent the soil nutrient availability information has been across time and may provide insight about nutrient depletion or accumulation as a result of the balance between the amounts of nutrients removed by the harvested crop and added via annual fertilization practices. In some years, abnormal soil test results can occur from sampling error or short-term environmental influences (e.g., extremely dry weather conditions). Should the most recent soil test results differ substantially from previous years' results, we would recommend using the old soil test results to make fertilization decisions if resampling fields is not an option.

The University of Arkansas recommends a 4-inch sample depth for wheat. Due to nutrient stratification (e.g., soil nutrient concentrations decline with increasing soil depth), collecting samples from a greater depth usually decreases the soil test values and may result in greater fertilizer rates being recommended. Collecting samples from less than a 4-inch depth would cause soil test values to be greater and would potentially reduce the amount of phosphorus (P) and potassium (K) fertilizer that would be recommended, leading to under-fertilization. University of Arkansas fertilization and liming recommendations are based on soil analysis and replicated field research results conducted by university scientists. You can obtain these recommendations by taking soil samples to your county Extension office.

As a general rule, soil samples should be collected following the same crop in a crop rotation sequence and at approximately the same time

(month) each year. This is especially important in fields rotated with rice because the soils may be flooded for two or three months during the summer and the anaerobic/flooded soil conditions can influence soil nutrient availability. Soil test P values tend to be slightly lower following rice compared with samples taken following soybeans in a 1:1 (rice:soybean) rotation. Other than this exception, research suggests that soil test P is consistent across the fall, winter and spring months, but pH and soil test K can fluctuate substantially. Soil samples collected in the fall (late October to mid-November), late winter (mid-February to early March) and spring (mid-April) showed the soil test K was always slightly higher when samples were collected in the fall.

The University of Arkansas fertilizer recommendations are sufficient to produce high wheat yields as nutrient availability is only one component influencing yield potential. Fertilizer recommendations for wheat are a combination of research trial results and soil nutrient management logic (e.g., building the fertility levels of depleted soils). Fertilizer recommendations provide an indication of the magnitude of yield response that can be expected and the probability that a significant yield increase will occur. Phosphorus and K fertilizer recommendations should be based on yield goals only when one is trying to replace the nutrients removed by the harvested crop. Soil test results are simply a nutrient availability index and not an absolute amount of total nutrients or plant-available nutrients in the soil. The nutrient removal rate used in University of Arkansas recommendations is calculated based on a 70 bu/acre wheat yield, although yields >70 bu/acre may be produced with these recommendations.

Lime and Soil pH

Soils used for irrigated crop production in Arkansas typically have soil pH values above 5.8. Fields that cannot be irrigated or are irrigated with surface water sources (streams, rivers or reservoirs) often require periodic liming to maintain the pH at a level that is not detrimental to crop growth and yield. Results from the University of Arkansas Soil Test Laboratory show that 75% to 80% of the acreage cropped to corn, cotton, grain sorghum, rice and soybeans, which are mostly irrigated, have pH values ≥5.8 and do not need lime. A portion of the Arkansas wheat acreage is grown in fields that are not irrigated (usually continuous wheat), and a significant proportion of the acreage has pH values that are very limiting (24% of acres have pH <5.4) or potentially limiting (23% have pH 5.4-5.7) to wheat production (http://arkansasagnews.uark.edu/608-1.pdf). As a general rule, wheat growth and yield may be reduced 20% to 50% when soil pH is <5.6. Maintaining soil pH at the proper level can optimize soil and fertilizer nutrient availability and minimize the incidence and severity of some diseases (e.g., Take-All).

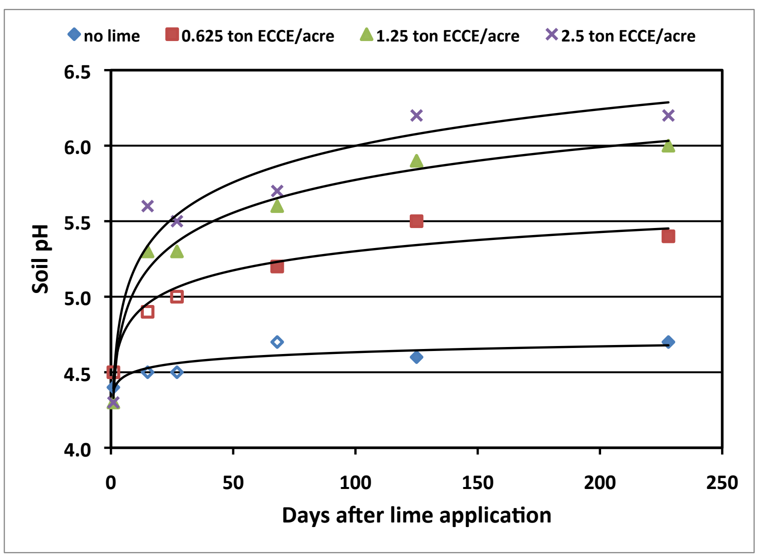
Some soft red winter wheat varieties are somewhat tolerant of acid soil conditions. Unfortunately there are no comprehensive screening programs that provide up-to-date acid soil or aluminum-toxicity tolerance ratings for modern soft red winter wheat varieties. However, some variety descriptions still include a general statement regarding acid tolerance (aluminum toxicity) or sensitivity that could be used to identify the acid tolerance or sensitivity of a few wheat varieties in the U.S.

The decision to apply lime should be based on current soil test results, the quality of irrigation water (in regard to alkalinity) used for rotation crop irrigation and the relative sensitivity of rotation crops to soil acidity and alkalinity. Soil samples collected during very dry periods may show lower than usual soil pH values which may influence the lime recommendation. During a calendar year, soil pH value may fluctuate as much as 1.0 pH unit (±0.5 units from the true pH mean). Collecting additional soil samples under more "normal" soil moisture conditions may show that the soil pH has increased or decreased slightly between sample times. Grid soil sampling is recommended to help identify pH and lime requirement gradients that may exist within a field due to variations in soil texture, land leveling activities or calcium (Ca) and magnesium (Mg) bicarbonate precipitation from irrigation water.

When lime is recommended, the recommended lime rate is best applied in advance of planting and mechanically incorporated into the plow layer. Application and incorporation in advance of planting will allow lime to begin neutralizing soil acidity before wheat growth begins. A common misconception is that lime must be applied weeks or months in advance of

planting to raise pH and benefit crop growth. Lime will begin to react with soil acidity shortly after it is applied provided that the soil is warm and moist (Figure 5-1). Although it is best to apply lime preplant and mechanically mix with the soil, the crop may still benefit if lime is applied post-planting and left on the soil surface. When lime is applied to and left on the soil surface, the pH of only the top inch or two of soil will likely be increased, while the subsoil (>2 inches deep) pH may be minimally affected. Various estimates suggest that the vertical movement of surface-applied lime is only 0.25 to 1.0 inch per year. If the field will not be tilled long-term more frequent lime applications at lower rates are warranted. While a postemergence, surface application of lime to wheat is not the best situation, it may still benefit the current wheat crop enough to justify its application and allow the lime to begin reacting with soil acidity to help maximize the benefit for the following crop.

Figure 5-1. Soil pH increase with time following lime application as affected by lime rate. Note that the lime rate is expressed as tons of effective calcium carbonate equivalent (ECCE) per acre. ***(Zhang et al., 2004)***



The University of Arkansas Division of Agriculture bases lime rate recommendations on soil Ca and pH (Table 5-1) with the soil Ca content providing an estimate of soil texture and cation exchange capacity. The recommended lime rates listed in Table 5-1 are for lime with average quality sold in Arkansas. On average, lime sold in Arkansas has a calcium carbonate ($CaCO_3$) equivalent (CCE) of 91.4% (4.0% standard deviation), an average fineness factor of 63.5 (10.5% standard deviation), an overall lime quality score [Effective Calcium Carbonate Equivalent (ECCE)] of 58%, and 43.8% (15.5% standard deviation) of the lime by weight is highly reactive (i.e., passes through a 60-mesh sieve). The recommended lime rate may need to be adjusted if the $CaCO_3$-based lime source is above or below average, a lime source other than $CaCO_3$ is used (e.g., CaOH, CaO or MgO) or the lime source is pelleted lime or liquid lime.

Liquid lime is simply fine $CaCO_3$ particles that are suspended in water that can be applied at relatively low rates as a suspension. The advantage of liquid lime is the fast reaction of the very fine (<100 mesh) lime particles when they are mixed with the soil. Pelleted lime is also very fine lime particles that are formed into a pellet using a binding agent which aids in uniform application, especially in windy conditions. The disadvantages of pelleted and liquid lime are that they are more costly and typically applied at much lower rates than ag lime. Although the lime may be highly reactive, the total amount of reactive lime applied is usually low (300 to 500 lb/acre) and insufficient to make a sizeable adjustment to soil pH with a single application. Regardless of the source, if the lime quality parameters

Table 5-1. Arkansas lime recommendations for winter wheat.

Soil Texture	Soil Test Ca	Below Optimum			Medium	Optimum
		<5.0	5.0 – 5.3	5.4 – 5.7	5.8 – 6.2	6.3 – 6.9
	ppm Ca	- - - - - - - - - - - - - - - lb ag lime/acre - - - - - - - - - - - - - - - -				
Sandy loam	≤500	4,000	3,000	2,000	0	0
Silt loam	501 – 1,500	5,000	4,000	2,500	0	0
Clay loam	1,501 – 2,500	6,000	5,000	3,000	0	0
Clay	≥2,501	7,000	6,000	4,000	0	0

(CCE and fineness) are known, the rate of pelleted lime or liquid lime that is equivalent to the average lime can be calculated. Pelleted lime is often applied at 300 to 500 pounds per acre, which is seldom if ever equivalent to 2,000 pounds of the average quality ag lime per acre. The lime rates based on the average quality ag lime listed in Table 5-1 can be adjusted when lime of higher or lower quality is used. An example of the calculations is shown in Example 5-1 and requires that one know the recommended rate and source of lime (ag lime, liquid lime or pelleted lime) as well as its purity and particle size distribution.

The two most common lime-related problems are not accounting for a field's spatial variability in lime requirement and uneven distribution of lime during application, which may result in under- or over-application of lime. Applying too much lime may increase soil pH to the point that the availability of some nutrients is reduced. The most common nutrient deficiencies observed following lime application include zinc (Zn) and phosphorus (P) deficiency of rice, Zn deficiency of corn and boron (B) deficiency of soybeans. All of these issues are of primary concern on silt and sandy loam soils, but can be effectively managed using a few simple guidelines.

1. Composite and/or grid soil samples should accurately represent the field.
2. The proper adjustments to the lime source and rate should be made based on quality, or the lime source and rate used should closely match the recommendation and be applied uniformly.
3. Soil test Zn levels should be Optimum, and/or rice and corn fertilization programs should include an appropriate Zn rate and source. For soybeans grown in areas where B deficiency is a problem, B should be included in the soybean fertilization program. Consult the appropriate crop production guide for specific recommendations.
4. The lime rate can also be reduced and applied in split applications at least one year apart. The soil should be resampled before the second half of the lime is applied.

Nitrogen

Nitrogen is a plant-essential element that is (1) required for plant growth and reproduction, (2) an essential component of amino acids, proteins and chlorophyll and (3) in the absence of fertilization, the most yield-limiting nutrient. No other nutrient can provide greater benefits for its proper use than N fertilizer, but the profitability of wheat production is closely linked to the proper rate, time, source and placement of N fertilizers. Current N rate recommendations are based on previous crop and soil texture to determine the total N rate required to maximize wheat yield.

Fall Nitrogen

Fall-seeded wheat generally does not require N fertilizer for establishment. Fall-applied N or preplant N can aid in the establishment of wheat under specific planting conditions and crop rotations, but should be managed on a case-by-case basis. Previous research has suggested the need for fall-applied N to help compensate for the large amount of crop residues produced by corn and grain sorghum, but recent data indicates that this added N may not be as beneficial as once thought

Example 5-1. Lime source comparison example (hypothetical data).

Lime Source	CCE†	Fineness Factor Information‡			ECCE§	Equal Rates¶
		10 mesh	60 mesh	Fineness Factor		
						- - - lb/acre - - -
Ag lime	91.5	49.2	43.8	63.5	58.1	2,000
Pelleted lime	92.7	6.4	93.6	96.2	89.2	1,302

†CCE, calcium carbonate equivalent.
‡The values in each column represent the percentage of material passing through a 10- and 60-mesh sieve. Fineness factor coefficients of 0, 0.4 and 1.0 multiplied by the percentage of lime having a diameter of >10-mesh, <10-mesh and >60-mesh, <60-mesh were used to calculate the fineness factor.
§ECCE, effective calcium carbonate equivalent, is the product of [fineness factor x (CCE/100)].
¶Equivalent rates, the amount of lime needed from each source to neutralize the same amount of acidity. Calculated by [((Ag lime ECCE/pelleted lime ECCE) × 2,000 lb ag lime/acre) = lb pelleted lime/acre].

and can potentially promote disease and lodging pressures later in the growing season. Incorporation of a large amount of crop residue from a summer grain crop may lead to immobilization of residual soil N. For crops other than flood-irrigated rice, fall-applied N has shown little or no benefit on wheat yield when late winter-applied N is properly managed. Preplant or fall-applied N can increase biomass and aesthetics of wheat following summer grain crops, but has little influence on final wheat yields under well-established, properly managed production practices. There is usually adequate inorganic N available in the soil for wheat following well-fertilized corn and grain sorghum crops.

The University of Arkansas Division of Agriculture recommends fall-applied N only when winter wheat follows flood-irrigated rice in the crop rotation (Figure 5-2). Wheat growth following flood-irrigated rice is usually poor for several reasons. First, following flood removal, previously flooded soils tend to have low amounts (<10 ppm) of inorganic N present. The large amount of rice straw and roots (even following burning) that is produced by rice may also immobilize soil inorganic N for an extended period. Finally, the anaerobic conditions created by flooding limit P availability too and inhibit vigorous wheat growth in the absence of proper fertilization and straw management. The combined effect of the low N and P availability is visually evident when the paddy area (poor growth) in the field is compared to the area where the rice levees (vigorous growth) had been located. Thus, it is recommended that 40 to 50 lb N per acre be applied in the fall when wheat immediately follows rice in the rotation sequence. Other considerations for preplant or fall-applied N based on planting date and grazing for grain are listed below.

Figure 5-2. The benefit of fall-applied N to the growth of winter wheat following flood-irrigated rice in the rotation.

Preplant N Considerations

1. **Late-planted wheat** – Should consider 30 lb N per acre preplant regardless of previous crop grown in rotation. Late-planted wheat is defined as planted after:

   (a) November 1 for northern Arkansas (north of Hwy 64)
   (b) November 10 for central Arkansas
   (c) November 20 for southern Arkansas (south of Pine Bluff)

2. **Wheat for grazing and grain** – Should consider 60 lb N per acre preplant.

3. **Wheat following flood-irrigated rice in the rotation** – Should receive 40 to 50 lb N per acre preplant or shortly after planting or crop emergence.

Late-Winter Nitrogen

The most efficient use of N fertilizer occurs from late-winter applications (e.g., February and early March). Addition of N fertilizer should be made immediately prior to the time of rapid vegetative growth near the tillering stage (Feekes 3-4). The maximum rate of N uptake occurs between jointing (Feekes 6) and flowering (Feekes 10.5), and it is critical that adequate N is available during this time of rapid vegetative growth. Research suggests that the late-winter N application can be delayed until Feekes stage 5 without harming wheat yield. This is likely true for the majority of soils, but on soils that are very N deficient, delaying N fertilization past Feekes stage 5 will likely result in yield loss due to poor tillering and/or abortion of tillers.

The recommended N rates for late-winter application to wheat are based on the soil texture and previous crop in rotation. Season total N rate recommendations are divided into two basic soil

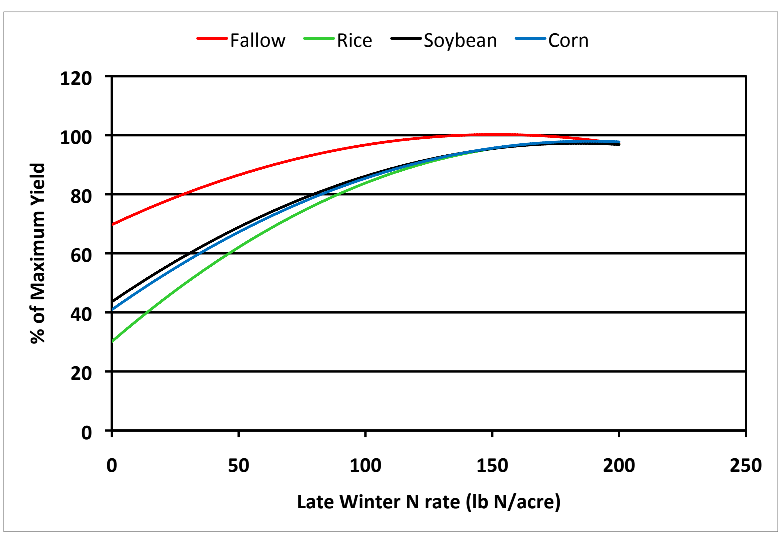
Table 5-2. Fall, late-winter N rate and season total N rate recommendations for winter wheat based on soil texture and previous crop.

Soil Texture	Previous Crop	Fall N Rate	Late-Winter N Rate	Total N Rate
		- - - - - - lb N/acre - - - - - -		
Silt and sandy loams	Fallow	0	90	90
	Rice	45	120	165
	All other†	0	120	120
Clay and clay loams	Fallow	0	140	140
	Rice	45	140	185
	All other†	0	140	140

†All other crops includes corn, cotton, grain sorghum and soybeans.

textures, loamy and clayey, and three previous crops including summer fallow, rice or all other summer crops (Table 5-2 and Figure 5-3). The late-winter N rate needed to produce near maximum yield is 90 lb N/acre following summer fallow or 120 lb N/acre following any other crop, including flood-irrigated rice. The season total N rate for wheat following flood-irrigated rice is greater than the other previous crop situations only because it also receives a recommendation for fall-applied N. Wheat produced on clayey soils receives a late-winter N rate recommendation of 140 lb N per acre following all crops in rotation and 120 lb N per acre following fallow.

Figure 5-3. Average wheat grain yield response to late-winter N rate as affected by previous crop.



Timing of the late-winter N applications is critical to ensure the maximal return on fertilizer input costs. Important yield components of wheat are set early in the growing season prior to the Feekes 6 growth stage (first node visible) including the number of tillers per area and the number of florets per spike. Therefore, it is critical that developing wheat plants are not deficient in nutrients, especially N, during this period of rapid vegetative growth and yield component determination. Although maximal yields can be obtained on well-drained soils with a single early application of N, splitting late-winter N rates greater than 90 lb N per acre can help to increase fertilizer N uptake efficiency (FNUE) by reducing the potential for losses due to leaching and/or denitrification (Table 5-3). Consider split applying late-winter N rates greater than 90 lb N per acre for winter wheat produced on poorly drained loamy- or clayey-textured soils. Divide the late-winter N rate in two equal splits with 50% of the total N rate applied at Feekes 3-4 and the remaining one-half applied near the Feekes 6 growth stage when the first nodes are visible at the base on the plant.

Poorly drained soils have the potential for N losses due to denitrification under prolonged wet conditions, and better FNUE and yields are often obtained, especially in years with above-average rainfall amounts, when N fertilizer is applied in split applications. Current research using N-15 indicates that single (applied early) and split applications of urea fertilizer to wheat grown on a poorly drained soil can produce comparable yields and FNUE (Table 5-3). There are advantages to single early applications of N for wheat production in Arkansas, including reduced applicator costs and time savings. Contrastingly, single early applications of N have an increased potential for N losses especially if spring growing conditions are unfavorable (i.e., cold and wet) and can accelerate maturation making wheat more prone to early heading and freeze damage. The one variable that no one can predict is the weather, and in recent years, we have come to learn that no two springs are alike.

Table 5-3. Fertilizer nitrogen uptake efficiency (FNUE), using an N-15 tracer, for several application times and rates on a Calhoun silt loam at the Pine Tree Research Station near Colt, AR.

Treatment†	FNUE	Yield
	% of Applied N	bu/acre
0 lb N	--	50
80 lb N Early	80	78
80 lb N Split	83	78
120 lb N Early	78	99
120 lb N Split	82	105
160 lb N Early	78	97
160 lb N Split	77	104

†N treatments were applied 100% early at the tillering stage (Feekes 3), or a split application of 50% at Feekes 3 and 50% when the first node was visible (Feekes 6).

Source: T. L. Roberts, unpublished data 2011-2013.

The timing of split fertilizer applications is determined by wheat growth stage and ultimately temperature and not calendar date. Springs that exhibit "normal" weather patterns with gradual and consistent increases in daily temperature generally allow producers to apply one-half of the late-winter N early and the remainder 2-3 weeks following the initial application. In years when temperatures are below normal and wheat development is slow, producers should monitor wheat development and growth stage to guide their second split application rather than the conventional 2-3 week timeframe. The data presented in Table 5-4 indicate the differences in calendar date for each growth stage critical for N fertilization and fertilizer application timing for the 2011-12 and 2012-13 cropping seasons. Wheat reached the Feekes 3 growth stage much earlier in 2012 and resulted in a much shorter time between split applications than was observed in 2013. A single early N fertilizer application time in 2013 would have remained in the soil longer than 2012 and would have been more prone to N losses due to the extended period between N fertilizer application and wheat uptake of N. The advantages of split-applying late-winter N are numerous, but it comes down to making sure the N fertilizer is available for the actively growing wheat crop. Spring temperatures and wheat variety can have a significant influence on how fast wheat develops and ultimately the timing of N fertilizer application. Split applications of N allow producers to apply a portion of the late-winter N early to stimulate late-winter tillering, but also monitor weather conditions and crop status to determine when the remainder of the N fertilizer should be applied. Research shows that in some years there may be no difference in wheat yield for an optimal N rate applied in one single application or split into two or three applications. Splitting late-winter N applications can reduce the potential of streaking at high N application rates, reduce the potential for N losses due to excessive rainfall or waterlogging of poorly drained soils.

Wheat that is N deficient near the time of heading may respond to N fertilization. Research suggests that small yield increases occur when 30 to 60 lb N per acre is applied to N-deficient wheat as late as Feekes stage 10 (Figure 5-4). When wheat is N deficient just prior to heading, application of 30 to 45 lb N per acre may be warranted provided that the wheat has good yield potential (e.g., other growth-limiting factors are not present).

Table 5-4. Timing of early single and split applications to the winter wheat variety Armor Ricochet based on growth stage on a Calhoun silt loam at the Pine Tree Research Station near Colt, AR, during the 2012 and 2013 growing seasons.

Year	Planting Date	Application Time†		Days Between Applications
		Single Early and First Split	Second Split	
2011-12	Oct. 7, 2011	February 21	March 15	21
2012-13	Oct. 22, 2012	March 5	April 4	30

†N treatments were applied 100% early at the tillering stage (Feekes 3), or a split application of 50% at Feekes 3 and 50% when the first node was visible (Feekes 6).

Figure 5-4. Wheat grain yield as affected by N fertilization at the early heading stage. ***(Mascagni et al., 1991)***

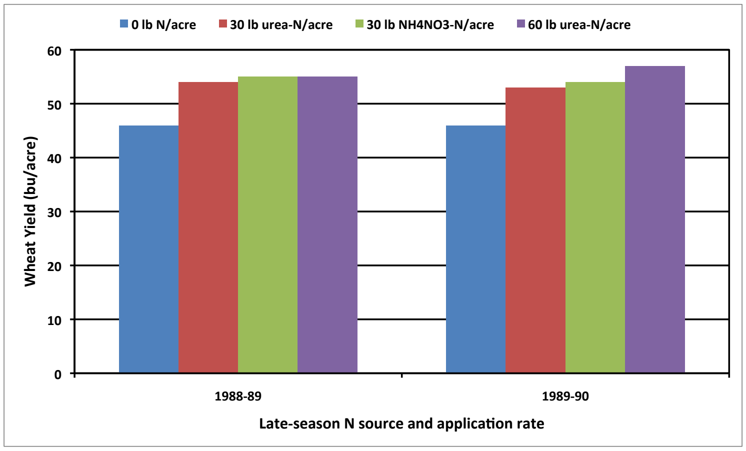
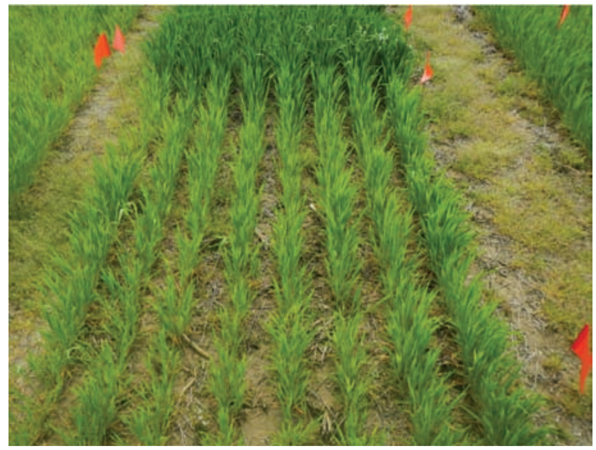


Figure 5-5. Nitrogen-deficient wheat in the foreground. Notice the pale green color and lack of vigor compared to the N-fertilized plot in the background.



Nitrogen deficiency symptoms in wheat can occur at any point during the growing season and are marked by a pale green appearance and yellowing of the older/lower leaves (Figure 5-5). Wheat plants exhibiting N deficiency will often have slow growth and spindly stems. As N deficiency progresses, the yellowing or chlorosis will progress up the plant from the older/lower leaves. Typically, leaves exhibiting chlorosis associated with N deficiency will begin to turn necrotic (brown), and the necrosis will follow the midrib down the leaf toward the leaf base. Senescence of older leaves can be mistaken for N deficiency when the canopy is sufficient to prevent sunlight from penetrating to the lower leaves. The overall vigor and appearance of the plant as dark green and healthy is usually an indicator that these older leaves are senescing (from age and shading) and not N deficient and will occur late in the season near heading.

Nitrogen Sources and Fertilizer Additives

Fertilizer sources of N for winter wheat production in Arkansas include ammonium sulfate, urea-ammonium-nitrate (UAN), urea and ESN (Environmentally Smart Nitrogen), but the source of N selected should be based on the cost per pound of N, application strategy, potential for N losses and application equipment available. Diammonium phosphate (DAP, 18-46-0) and monoammonium phosphate (MAP, 11-52-0) also contain N, but are not typically used to supply a large portion of the season total N requirement for wheat. As with any fertilizer application, it is important to consider soil texture (soil drainage) and weather conditions (i.e., temperature, rainfall, etc.) when selecting the proper N source for your production system.

Urea is widely available across Arkansas, has a high N analysis (46% N) and is easily applied, but can be prone to ammonia volatilization losses if environmental conditions are conducive. When spring temperatures increase and the soil surface is moist before urea application, there is a significant increase in the N loss potential from surface-applied urea and the use of a recommended urease inhibitor such as NBPT [N-(n-butyl) thiophosphoric triamide] is suggested. Table 5-5 shows the frequency and magnitude of yield increases when wheat was fertilized with NBPT-treated urea or urea (no NBPT). Although there are no definitive guidelines for the use of NBPT on surface-applied urea, there are some scenarios that would promote its use including high forecasted daily temperatures (>70˚F) and relative humidity (>70%), moist soil conditions, windy conditions, small wheat plants and no significant rainfall (0.25-0.50 in) forecast in the next 7 days.

Ammonium sulfate is an excellent N fertilizer source with relatively low N loss potential and a good N source for soils that have exhibited S deficiency, but has a lower N analysis (21% N, 24% S) and is generally more costly per pound of N than urea. Ammonium sulfate has minimal N loss potential via ammonium volatilization when

Table 5-5. Winter wheat grain yield as affected by the use of NBPT-treated urea compared to urea (no NBPT) across 24 N applications. Each N source was applied in a single application of a suboptimal N rate of 75 lb N/acre.

Category	N Applications	Frequency	Urea	Urea+Agrotain
Yield Increase	#	% (of 24)	Wheat yield averaged across sites, bu/acre†	
All sites and times	24	--	64 b	66 a
≤2.5 bu/acre	14	58	69 a	70 a
2.6 – 5.0 bu/acre	5	21	58 b	62 a
5.1 – 7.5 bu/acre	3	13	58 b	64 a
>7.5 bu/acre	2	8	48 b	61 a

†Means within the same row followed by the same letter are not different.
Source: Slaton et al. (Crop Management, 2011)

surface-applied to the soil. Blending of ammonium sulfate with urea has become common for the first late-winter N application, and producers are able to reap the benefits of the N as well as the S on sandy soils that are prone to S deficiency.

Urea-ammonium-nitrate (28% to 32% N) is a liquid fertilizer formulation where roughly one-half of the N is in the urea form, one-quarter is in the ammonium form and one-quarter is in the nitrate form. Although UAN may have a per unit of N cost comparable to urea, it is also prone to ammonia volatilization losses and can burn plant leaves if application rates or temperatures are high enough. In cool weather where the daily high temperature does not exceed 70°F, rates as great as 50 lb N per acre can be safely applied. When temperatures exceed 70°F or the wheat has reached the jointing stage (Feekes 6), it is recommended to keep N rates below 40 lb N per acre as considerable leaf burn can occur. Application of UAN via streamer bars can reduce the potential for leaf burn.

A slow-release fertilizer product known as ESN (Environmentally Smart N) is now available for application to field crops in Arkansas. ESN is a polyurethane (plastic polymer) coated urea prill, which slowly supplies N to the growing wheat plants. Since ESN is a slow-release fertilizer, there is likely no benefit to split applications, but there are some application timing limitations that must be considered for optimal use. There has been limited research conducted in Arkansas using ESN as a N fertilizer source for winter wheat, although several other states have conducted more extensive research and have developed recommendations for its use. The following is a brief summary of the guidelines suggested by other states and information from the limited amount of Arkansas-specific research. When wheat breaks winter dormancy, the wheat plant's demand for N during the stage of rapid vegetative growth increases gradually and peaks between Feekes stages 5 and 10. If ESN will be applied after wheat breaks winter dormancy, it should be blended with urea to ensure sufficient N is immediately available to the growing wheat. Research in Arkansas (Table 5-6) indicates that ESN must be blended (50:50) with urea and applied very early, prior to green-up, in order to achieve yields similar to urea or NBPT-treated urea. Applications of ESN as the sole N source resulted in wheat yields that were numerically lower than urea and NBPT-treated urea regardless of the application time. Arkansas

Table 5-6. Winter wheat yield means for each N source and time of application combination at the Pine Tree Research Station during the 2007-2008 growing season.

N Source†	Feb. 10	Feb. 28	March 12	March 25
	- - - - - - - - - - bu/acre - - - - - - - - - -			
Control	23			
Standard	63			
Urea	57	56	50	49
Agrotain	55	57	54	60
ESN + Urea	55	50	44	44
ESN	46	45	45	40

†Control = no N; Standard = 125 lb urea-N/acre applied in two split applications; urea (75 lb N/acre); Agrotain (75 lb N/acre) is urea treated with Agrotain; ESN is Environmentally Smart N fertilizer (75 lb N/acre); and ESN + Urea is a 50:50 mixture of each fertilizer (75 lb N/acre).
Source: Slaton et al., 2009.

research and surrounding state ESN-use guidelines suggest that, if ESN is to be applied to winter wheat, the ESN should be applied before wheat breaks winter dormancy (Feekes growth stage 2 or 3) or should be blended with urea and applied shortly after green-up to ensure adequate time for N release. When applied postemergence to the soil surface, there should be adequate wheat growth or previous crop residue to hold the polymer-coated urea prills in place (prevent physical movement in case of hard rain).

Diammonium phosphate and monoammonium phosphate are commonly applied and incorporated preplant to meet the P requirements for winter wheat, and the resulting N additions are immediately plant available but are often in such small quantities (<25 lb N acre) that they are not counted toward the recommended total N rate. Fall application of DAP and MAP can provide some N for the growing wheat crop, but the fall-applied N is usually taken up less efficiently than late-winter applied N.

Phosphorus and Potassium

Winter wheat is one of the most P-responsive crops grown in Arkansas. The cool temperatures and moist soil conditions experienced from January through March often limit P movement and P uptake at the time of rapid crop growth. In contrast, wheat response to K fertilization is usually less dramatic, but K is still an important nutrient for wheat production. Ensuring that a sufficient supply of soil and/or fertilizer P and K is available to the developing crop is an important consideration for producing a high-yielding wheat crop and will aid in the efficient use and uptake of N. The University of Arkansas soil test-based fertilizer recommendations for P and K are for (1) a 4-inch deep soil sample, (2) the Mehlich-3 soil test method and (3) the nutrient concentrations of the extracts are determined with an inductively coupled plasma atomic emission spectrophotometer (ICP-AES).

Phosphorus deficiency symptoms may appear shortly after wheat emergence and, when the P deficiency is severe, remain noticeable until maturity. Severe P deficiency will limit fall tillering, making the wheat seedling appear very spindly or thread-like (Figure 5-6). The most well-known and noticeable P-deficiency symptom is the reddish-colored leaves or leaf tips and edges. The reddish color is not always a good indication of a yield-limiting P deficiency. Wheat seedlings may express this reddish coloration when the soil is cool and wet and the plant has exhibited vigorous, early-season growth (Figure 5-7). Wheat that has received ample P applied at planting may also have reddish-colored leaves. Thus, the relative amount of plant growth along with the presence of reddish-colored leaves, soil test results and the implemented fertilization practices should all be considered when evaluating whether additional P fertilizer may be needed. Some varieties tend to show more purpling during cool and wet conditions even though P levels are adequate.

Figure 5-6. Phosphorus-deficient wheat seedlings in late February showing lack of tillering and growth and reddish coloration on leaves.

Figure 5-7. Wheat that has ample tillering and growth in late February exhibiting reddish coloration of the leaf tips associated with phosphorus deficiency induced by poor growing conditions including cold weather and waterlogged soil. Additional phosphorus fertilizer is not likely needed on this soil.

Phosphorus-deficiency symptoms may also include reduced plant height and leafiness and delayed heading (e.g., maturity). Application of more than sufficient amounts of P will not speed up the rate of plant development and allow for earlier maturity and harvest.

The P-fertilizer recommendations for wheat and other small grains are listed in Table 5-7. A summary of soft red winter wheat research at 37 sites suggests that the critical soil test P concentration is 36 ppm (72 lb/acre, Figure 5-8). The frequency of positive yield responses to P fertilization decreases as soil test P increases (Table 5-8). For example, five of seven or 71% of the research sites with a Very Low soil test

Figure 5-8. Percent relative grain yield (%RY) of winter wheat that received no P fertilizer relative to the maximum yield of wheat receiving P fertilizer across 37 site-years of research on silt loam soils. ***(Slaton, unpublished data)***

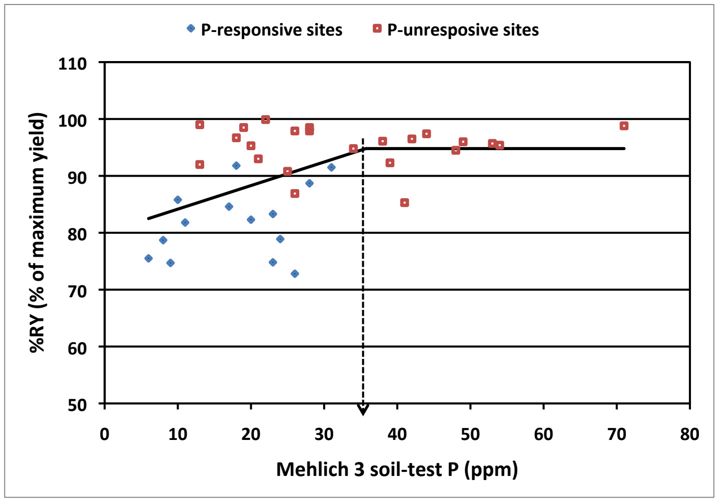


Table 5-7. University of Arkansas phosphorus and potassium fertilizer recommendations for small grains and wheat followed by double-cropped soybeans based on Mehlich-3 soil test P (as determined by ICAP) and K.

Nutrient	Soil Test Level	Soil Test Concentration	Oats	Winter Wheat	Wheat and Double-Crop Soybeans†
Phosphorus		ppm P	- - - - - - - - - - - - lb P_2O_5/acre - - - - - - - - - - - -		
	Very Low	≤15	90	100	120
	Low	16 – 25	60	70	90
	Medium	26 – 35	50	50	50
	Optimum	36 – 50	0	0	0
	Above Optimum	≥51	0	0	0
Potassium		ppm K	- - - - - - - - - - - - lb K_2O/acre - - - - - - - - - - - -		
	Very Low	≤60	140	140	180
	Low	61 – 90	90	90	120
	Medium	91 – 130	60	60	80
	Optimum	131 – 175	0	0	60
	Above Optimum	≥176	0	0	0

†Wheat followed by double-crop soybean P and K fertilizer recommendations include the fertilizer amounts for both crops. The cumulative fertilizer rate can be applied in the fall.

Table 5-8. Summary of 37 trials conducted between 2002 and 2012 describing soybean yield response to P fertilization by soil test level.

Phosphorus Level	Soil Test Range	Sites Tested		Average Yield (Unresponsive Sites)		Average Yield (Responsive Sites)			
		Total	Responsive	No P	Fertilized	No P	Fertilized	Loss	
	ppm P†	#	% of total	- - - - - - - - - - - - - - - bu/acre - - - - - - - - - - - - - - -					%
Very Low	≤15	7	71	75	78	50	63	13	21
Low	16 – 25	12	50	79	82	55	65	11	17
Medium	26 – 35	8	38	70	73	62	73	11	15
Optimum	36 – 50	7	0	63	67	--	--	--	--
Above Optimum	≥51	3	0	66	69	--	--	--	--

†Soil test units are listed as parts per million (ppm or mg/kg) and may be converted to pounds per acre by multiplying the ppm value by 2 (ppm × 2 = lb/acre). This calculation assumes that an acre-furrow-slice of soil weighs 2 million pounds.

P level benefited from P fertilization and yielded, on average, 13 bu/acre more than wheat that received no P. The magnitude of yield increase from P fertilization gradually decreases as soil test P increases. Phosphorus fertilization at 10 sites with soil test P levels considered Optimum or Above Optimum has not significantly benefited wheat yields in Arkansas.

The P needs of winter wheat and other small grains can be satisfied with any of the commercially available granular or liquid formulations of P fertilizer including triple superphosphate (0-46-0), diammonium phosphate (DAP, 18-46-0), monoammonium phosphate (MAP, 11-52-0) or MicroEssentials (10-40-0-10%S-1%Zn). Some fertilizer dealerships provide bulk liquid P and K fertilizers rather than granular forms of P and K fertilizer. The base formulation of these liquids is usually MAP. Some research suggests that liquid P fertilizer formulations sometimes enhance P movement in the soil, increase crop P uptake and result in greater wheat grain yield increases compared to granular P fertilizers applied at equal nutrient rates. The advantage of soil-applied liquid P sources is most often observed on soils that require P (e.g., suboptimal soil test P) and contain free $CaCO_3$ (calcareous soils) rather than neutral to slightly acidic soils. The majority of Arkansas soils are alkaline and contain only trace amounts of free $CaCO_3$. Thus, liquid and granular P-fertilizer formulations are expected to perform similarly when soil test results indicate that P is needed.

The University of Arkansas Division of Agriculture does not recommend the use of fertilizer additives that claim to enhance P availability (or prevent P fixation) after P is applied to and mixed with the soil. Evidence that such products are consistently beneficial or perform according to the manufacturer's claims has not yet been established in unbiased, university research. The majority of Arkansas research suggests that broadcasting 60 lb P_2O_5 per acre is usually sufficient to produce near maximal wheat yields in most soils. Higher P rates are recommended for soils that have Very Low and Low P levels to help build the soil's P availability.

Phosphorus fertilizer should be applied shortly before or after wheat is planted. Arkansas research indicates that P fertilizer may be applied from before planting until early March without yield loss (Table 5-9). Although the research reports did not provide the growth stage for each P application time, wheat usually has not developed beyond Feekes stage 5 by early March. Phosphorus fertilizer is best applied shortly before or after wheat is planted and preferably no later than Feekes stage 3 since P is critical for proper tiller formation and development. Application of sufficient P to late-planted wheat is critical to promote adequate root and shoot growth before the colder winter temperatures cause wheat to become dormant. The results in Table 5-9 demonstrate that P fertilizer can be successfully banded, preplant incorporated or surface-applied postemergence.

The greatest wheat growth and yield responses to P fertilization are likely to occur when wheat follows flood-irrigated rice in the crop rotation on soils that have Very Low soil test P and pH <6.5. Regardless of the previous crop, P availability to wheat tends to decrease when soil pH is less than 6.0. When soil P availability is Very Low, consider using a P source that includes N (DAP, MAP or MESZ) because the addition of P and N together usually results in more vigorous early-season growth than either nutrient applied alone. Ensuring that poorly drained soils have adequate surface drainage is critical to facilitate wheat uptake and use of soil and fertilizer nutrients.

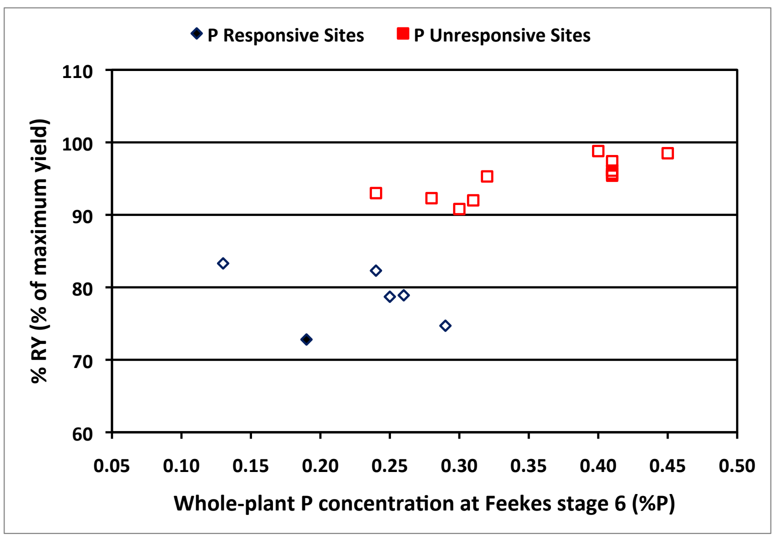
The winter wheat tissue P concentration can provide an indication of the plant's P nutritional status. A limited amount of data suggests that

Table 5-9. Wheat yield response to phosphorus fertilizer (60 lb P_2O_5/acre) application time on a poorly drained Dewitt silt loam soil. ***(Correll et al., 1995)***

P Fertilization Time	1991-1992	1992-1993	1993-1994
	- - - - - - - - - bu/acre - - - - - - - - -		
No P	75	43	83
Preplant incorporated	92	42	90
Band with seed	94	57	89
Surface broadcast after seeding	93	50	91
Early December	94	49	92
Early February	94	48	91
Early March	90	53	93
Early April	85	51	89
LSD0.05	8	9	5

whole-plant P concentrations at Feekes stage 6 of less than 0.30% P indicate P deficiency (Figure 5-9) and can usually be identified by suboptimal soil test P values. At Feekes stage 10.1 to 10.5, whole-plant P concentrations less than 0.20% also suggest that P is limiting wheat yield. Based on our limited research data, wheat growth stage is an important consideration for monitoring and interpreting wheat tissue P concentrations. Based on information from published critical and sufficiency values (Table 5-10), whole-plant concentrations <0.15% P would always be considered as P deficient, but during the tillering and jointing stages, whole-plant P concentrations should be above 0.30% P.

Figure 5-9. Percent relative grain yield (%RY) of winter wheat that received no P fertilizer (relative to the maximum yield of wheat receiving P fertilizer) and the associated whole-plant P concentration at Feekes stage 6 for 17 research sites that had whole-plant samples collected for tissue analysis. ***(Slaton, unpublished data)***



Potassium fertilization of winter wheat has received less research attention because, as a general rule, wheat tends to be less responsive to K fertilization than N and P fertilization. Potassium deficiency symptoms of wheat are seldom observed in Arkansas, but would typically appear during the rapid growth period (e.g., tillering to heading) that occurs in late winter and early spring (March-May) following N fertilization. Similar to other grass crops, the symptoms would be most noticeable on the lower or oldest leaves and would include chlorotic (yellow) or necrotic (brown) leaf margins starting at the leaf tip and progressing along the leaf margins toward the leaf base.

Following soil test guidelines for K will ensure that the wheat crop has sufficient K available to achieve near maximum yield potential (Table 5-7). Although very little research has been conducted to examine wheat yield response to K application rate or time, K fertilizer applied before Feekes stage 5 should be sufficient to maximize plant growth and yield.

When soybeans will be double-cropped following wheat, the total P and K fertilizer requirement can be applied directly to the winter wheat. The rate of fertilizer application is more important than the time of application for wheat and double-crop soybean production (Table 5-11). Splitting the total nutrient rate (e.g., two separate applications) between the wheat and soybeans should

Table 5-10. Critical and sufficiency ranges for interpreting tissue nutrient concentrations for small grain crops including wheat and oats. ***(Plank and Donohue, 2011)***

Level	Nutrient									
	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B
	- - - - - - - - - - - - - % - - - - - - - - - - - - -						- - - - - - - - - - ppm - - - - - - - - - -				
Critical†	3.0	0.15	2.0	0.15	0.10	0.10	25.0	15.0	15.0	3.0	1.0
Sufficiency‡	4.0–5.0	0.2–0.5	2.5–5.0	0.2–1.0	0.14–1.0	0.15–0.65	30–200	20–150	18–70	4.5–15	1.5–4.0

† Nutrient concentrations lower than the critical values are considered deficient.
‡ Nutrient concentrations within the sufficiency level are considered adequate for normal plant growth and yield. Nutrient concentrations below the minimum value of the sufficiency range are considered low or deficient.

Table 5-11. Winter wheat and double-crop soybean response to P and K fertilization strategy and rate.*(Slaton et al., 2010a, 2010b)*

Fertilization Strategy†			Phosphorus		Potassium	
Wheat	Soybeans	Total	Wheat	Soybeans	Wheat	Soybeans
- - - - - - - - lb P_2O_5 or K_2O/acre - - - - - - - -			- - - - - bu/acre - - - - -		- - - - - bu/acre - - - - -	
0	0	0	40	24	44	19
30	30	60	42	25	46	25
60	0	60	43	24	45	27
120	0	120	51	32	49	26
90	60	150	47	29	50	27
150	0	150	54	29	47	31
		LSD0.10	4	4	NS‡	5

†Strategy refers to the amount of P or K fertilizer applied before wheat was planted (Wheat) or after wheat was harvested (Soybeans) with Total being the total amount applied prior to planting soybeans after wheat harvest.
‡NS, not statistically significant.

be considered if the wheat straw will be baled because a larger proportion of the applied P and K will be taken up by the wheat and subsequently removed when the straw is baled and removed from the field. When splitting the fertilizer between these two crops, an important generalization is that wheat tends to be more responsive to P fertilization and soybeans tend to be more responsive to K fertilization.

Wheat grain removes about 80% of the aboveground P and 20% of the aboveground K with the remainder of the P and K contained in the wheat straw. Wheat grain usually has average concentrations of 0.36% P and 0.48% K, which removes the equivalent of 0.50 lb P_2O_5 and 0.35 lb K_2O per bushel of wheat grain. The nutrient concentration of wheat straw is likely to be more variable than that of wheat grain, but values from the International Plant Nutrition Institute (http://www.ipni.net/article/IPNI-3296) suggest that wheat straw typically contains 0.16 lb P_2O_5 and 1.2 lb K_2O per bushel of wheat grain produced. Estimates based on wheat straw tonnage are 3.7 lb P_2O_5 and 29 lb K_2O per ton of wheat straw. Both grain and straw nutrient concentrations may be influenced by factors such as variety, native soil fertility and fertilizer management practices, but straw nutrient concentrations are usually more affected by these factors.

Secondary Nutrients

The Ca and Mg requirements of winter wheat are usually met by maintaining soil pH at near optimal values (>5.8). Deficiencies of Ca and Mg are rare in Arkansas and are most likely to occur on acidic, sandy-textured soils. Soil Mg concentrations are sometimes low (≤30 ppm Mg) in fields that are not irrigated (eastern Arkansas) or in western Arkansas. In these fields, 30 to 50 lb Mg per acre can be supplied with dolomitic limestone if the pH is below optimum or potassium-magnesium sulfate (~11% Mg) if K is also needed. Other Mg sources may also be available and should be discussed with someone knowledgeable in fertilizers.

The importance of the soil Ca:Mg ratio has become an issue in recent years. Questions are being asked about the soil Ca:Mg ratio and how it relates to the need for Ca or Mg fertilization of Arkansas crops, including winter wheat. The "Basic Cation Saturation Ratio" concept suggests that optimal crop growth and yield occur when the soil's cation exchange sites are occupied by ideal amounts of Ca, Mg and K. The original concept suggested that a soil's cation exchange sites should be occupied by 65% Ca, 10% Mg and 5% K, which yields ratios of 6.5:1 for Ca:Mg, 13:1 for Ca:K and 2:1 for Mg:K. The basic cation saturation of soil that is considered ideal has evolved over

time and may differ slightly from the values given above. Common interpretations range from 60%-80% Ca, 10%-20% Mg, 2%-5% K and 10%-15% H. A recent summary of research involving the basic cation saturation ratio concept showed that crops can produce high yields across a wide range of Ca:Mg, Mg:K and Ca:K ratios.

The most common situations involving the Basic Cation Saturation Ratio approach is that the soil Mg saturation in Arkansas soils is too high and results in a narrow Ca:Mg ratio, and the high Ca and/or Mg contents of many Arkansas soils coupled with Low to Medium levels of K result in Ca:K or Mg:K ratios that are considered less than optimal for K availability. When the Ca:Mg ratio is too narrow, proponents of the Basic Cation Saturation Ratio approach commonly recommend that gypsum ($CaSO_4$) be applied to supply Ca. Based on the literature and the fact that most of the groundwater irrigated soils in eastern Arkansas have pH values between 6.5 and 8.2, the University of Arkansas Division of Agriculture does not recommend the application of gypsum as a Ca source to these soils.

Sulfur

Sulfur (S) is the secondary nutrient that is most likely to limit wheat growth and yield. Sulfur-deficient wheat usually has chlorotic (e.g., light green to yellow) leaves (Figures 5-10 and 5-11). During the early season the entire plant may be chlorotic and produce few tillers. Mid- to late-season, S-deficient plants will be stunted (short) and the top or youngest leaves may show the most dramatic chlorosis. Symptoms of S deficiency typically occur in early March as plants break dormancy and begin rapid vegetative growth. The effect that S deficiency has on tillering may depend on the growth stage that S deficiency started and the duration of the deficiency. Wheat plants growing in waterlogged soils may show symptoms similar to that described for S deficiency.

Sulfur deficiency of winter wheat occurs primarily on well- or excessively drained soils that have a sandy texture. Sulfate (SO_4), the plant-available form of S found in soil, may leach in sandy soils, which also tend to be low in organic matter and plant-available S. A rule of thumb that has been used for years is to apply S to soils that have <10 ppm SO_4-S on the soil test report. However, this rule of thumb is not highly accurate as many poorly drained soils, which are highly unlikely to respond to S, commonly have soil test SO_4-S <10 ppm. Well-drained soils that contain <5 ppm soil test SO_4-S may be a better estimate of the need for S fertilization. Because SO_4-S is mobile in the soil, soil test S values may not accurately represent the soil S availability for the entire growing season. Sulfur deficiency is most likely to occur when above-normal precipitation is received. Field history and soil texture should be used along with soil test S to determine whether S fertilization is needed.

Figure 5-10. Sulfur-deficient wheat during the jointing stage showing chlorosis of the entire plant with the yellowing being most pronounced on the upper leaves.

Figure 5-11. Sulfur-deficient wheat located in a field with both sandy- and loamy-textured soils. Notice the yellowing of the upper leaves indicating S deficiency.

Tissue analysis can help detect S deficiency (Table 5-10). Sulfur is considered deficient when the tissue concentration is <0.10% S and low when tissue contains 0.10% to 0.15% S. A N:S ratio >18:1 also indicates that S may be deficient. The optimal N:S ratio range for winter wheat is considered to be 10:1 to 15:1.

The most common source of S used on wheat is ammonium sulfate (21% N and 24% S), but other sources such as gypsum (calcium sulfate, nutrient concentrations vary among sources, 19%-23% Ca and 15%-20% S), potassium sulfate (50% K_2O and 17% S), potassium magnesium sulfate (22% K_2O, 22% S and 11% Mg) and elemental S (90% S) may also be viable S sources. Elemental S (S^0) is a slowly available form of S (i.e., contains no SO_4-S) and needs to be preplant incorporated at rates of 50 to 100 lb S^0/acre to allow sufficient time for the elemental S to undergo microbial oxidation to produce plant-available S before cold winter temperatures inhibit soil microbial activity. Elemental S is also a soil acidulent and should only be used on soils that have near neutral or alkaline pH. The form of elemental S (e.g., powder, pastille or flakes) applied is an important consideration since some products break down (e.g., oxidize) into sulfate very slowly. For the immediately available S fertilizers, application of 5 to 20 lb S/acre is usually sufficient to supply the S requirement for wheat on most soils (Table 5-12).

Application of an immediately available form of S along with the first late-winter N application (e.g., February) typically provides sufficient S for the wheat crop. Application of S shortly before or after planting may also provide sufficient S, but on well-drained or excessively drained soils, the available S may be leached before wheat resumes growth in the late winter. Research on sandy soils suggests that S applied in February or March with the first N application corrects S deficiency and prevents yield loss (Table 5-13). Regardless of when S is applied, wheat should be continually monitored for S deficiency symptoms when soil and climatic conditions are favorable for leaching.

Table 5-12. Winter wheat response to S application rate on a Roxanna sandy loam at Kibler, AR. *(Wells et al., 1986)*

S Rate	Tissue S		Grain Yield	
	+S (as K_2SO_4)	No S (KCl)†	+S (as K_2SO_4)	No S (KCl)†
lb S/acre	- - - - - % S - - - - -		- - - - bu/acre - - - -	
0	0.11‡		15‡	
5	0.25	0.05	44	15
10	0.35	0.07	40	19
20	0.42	0.05	36	19
40	0.50	0.08	36	19

† The KCl treatment contained no S, but provided equal amounts of K as the K_2SO_4 treatment at each S addition rate.

‡ Statistical analysis was performed as single-degree-of-freedom contrasts to compare selected treatments or groups of treatments.

Table 5-13. Wheat yield response to S application time, averaged across S application rates of 10, 20 and 40 lb S/acre, on a Roxanna fine sandy loam at Kibler, AR. *(Wells et al., 1996)*

S Application Time	Grain Yield
	- - - - bu/acre - - - -
No S	68
8 February	76
23 February	72
9 March	80
22 March	78
4 April	73
25 April	71
LSD0.05	6

Micronutrients

Micronutrient deficiencies of winter wheat have not been reported or knowingly observed in Arkansas. Boron (B) and zinc (Zn) deficiency are the most common micronutrient deficiencies observed in other crops grown in Arkansas, but to date have not been documented in winter wheat. A limited amount of Zn and B fertilization research in Arkansas has shown no wheat yield

Table 5-14. Winter wheat tissue concentration and yield response to B and Zn fertilization. ***(Slaton et al., 2010a)***

Treatment	Following Rice†			Following Soybeans†		
	Tissue B	Tissue Zn	Yield	Tissue B	Tissue Zn	Yield
	- - - - - - - - ppm - - - - - - - -		bu/acre	- - - - - - - - ppm - - - - - - - -		bu/acre
Control	2.1	15.8	56	2.5	17.1	41
10 lb Zn/acre (preplant)	2.2	17.7	55	3.0	25.4	42
1 lb Zn/acre (foliar)	2.2	19.4	56	2.1	17.3	37
1 lb B/acre (preplant)	3.1	15.6	58	4.8	17.3	40
0.33 lb B/acre (foliar)	2.7	14.8	56	3.6	18.3	38
10 lb Zn + 1 lb B/acre	3.5	14.7	55	4.2	25.8	39
LSD0.10	0.7	2.1	ns	0.7	3.8	ns

†Both were silt loam soils that had a soil pH of 6.2 and Mehlich-3 extractable Zn of 1.2 ppm.

benefit from soil or foliar application of B and Zn (Table 5-14). Thus, the University of Arkansas Division of Agriculture has no micronutrient fertilization recommendations for winter wheat or other small grains. Supplying these micronutrients at recommended rates to crops that are grown in rotation with winter wheat likely provides sufficient B and Zn to winter wheat. If a micronutrient deficiency is suspected, the soil and plant sampling procedures outlined in the "Troubleshooting" section should be followed to document the deficiency.

Tissue Analysis and Troubleshooting

Tissue analysis is an excellent resource for assessing the nutritional status of winter wheat, provided that the results are properly interpreted and, perhaps more importantly, the limitations of tissue analysis and the established critical nutrient concentrations are recognized. Critical tissue nutrient (e.g., values below the listed critical concentrations are considered deficient) concentrations and sufficiency ranges are listed in Table 5-10. These diagnostic values are often a combination of research-based information and the professional experience of agronomists that have a great deal of experience examining nutritionally stressed crops and the resultant plant analysis and soil test results. Some nutrient deficiencies are quite rare, and the critical concentration may simply represent the lowest observed nutrient concentration of samples submitted from a survey of commercial fields. Wheat plant samples collected in Arkansas fertilization trials represent a broad range of wheat growth stages and soils and show that whole-plant wheat samples commonly contain B and Zn concentrations that are below the listed sufficiency range. A limited amount of research evaluating wheat yield response to B and Zn in eastern Arkansas shows no yield benefit from Zn or B fertilization of wheat (Table 5-14). The tissue concentrations of most nutrients in wheat plant samples decreases as the plant develops from the early tillering (Feekes 3) to heading stages (Feekes 10.5).

Proper interpretation of wheat tissue analysis results begins with collecting the proper tissue. In addition to collecting the proper tissue, additional information that can be critically important to the proper diagnosis includes the growth stage, location of symptoms on the plant, the pattern of symptoms in the field, variety, current (wheat) and previous crop management history (e.g., herbicides, lime, fertilization, irrigation source, etc.), climatic conditions, soil moisture and weather conditions, and management practices that have been implemented in adjacent fields.

Table 5-15. Instructions for collecting wheat and other small grain plant samples to be submitted for diagnostic nutrient analysis.

Growth Stage	Plant Sampling Instructions
Seedling to tillering stage	Cut tissue from 40 to 100 seedlings/per composite sample about 1 inch above the soil surface. Discard dead leaves. If the seedling tissue is dusty or dirty, briefly rinse the sample in clean water while the tissue is still fresh/green. The number of seedlings (40 to 100) needed for a proper sample decreases as plant size increases.
Jointing to flag leaf emergence	Collect either whole aboveground plant samples (cut 1 inch above the soil surface) or the top one-half of the plant (leaves and stem) from at least 15 to 25 plants. If the seedling tissue is dusty or dirty, briefly rinse the sample in clean water while the tissue is still fresh/green. Record the plant growth stage.
Flag leaf emergence to flowering	Collect the flag leaves from 20 to 30 plants. Record the growth stage. Leaf samples can also be collected after grain fill begins, but the interpretation of the results may be compromised. If the leaves are dusty or dirty, briefly rinse the sample in clean water while the tissue is still fresh/green.

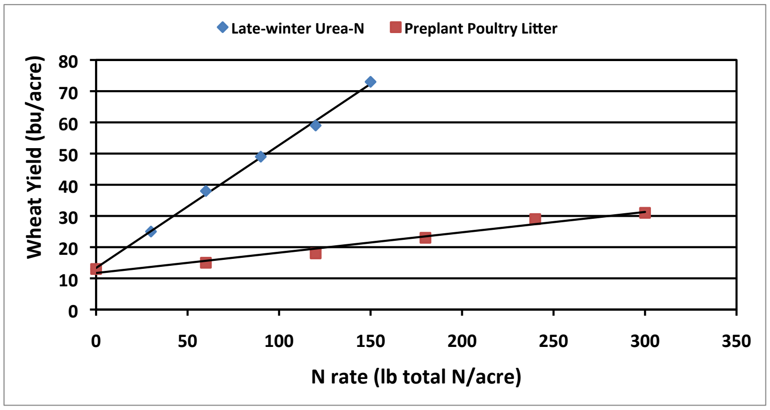
Wheat tissue that should be collected and submitted for nutrient analysis is outlined in Table 5-15. To diagnose the potential for poor growth caused by nutrient deficiency, separate wheat samples should be collected from the field areas that show (1) poor growth or nutrient deficiency symptoms and (2) good growth (no visible symptoms or problems). When the symptoms are present and vary in severity, collecting three separate samples of wheat plants that exhibit severe, moderate and no symptoms may also prove beneficial. The most accurate interpretation of nutrient concentrations may be for samples collected at or near Feekes stages 5 and 10.1. However, note that fertilization to correct a nutrient deficiency and prevent associated yield loss is unlikely for samples collected at Feekes stage 10.1.

When troubleshooting a potential plant nutrition related problem, soil samples should also be collected at the same time and from the same general locations that plant tissue samples are located. Soil samples should be collected from the 0- to 4-inch soil depth and submitted for routine analysis. Soil electrical conductivity and nitrate may also be of interest for troubleshooting problems.

Biosolids and Manure

Biosolids and poultry litter contain appreciable amounts of many nutrients, including N, P and K, and may be used as an alternative to inorganic P and K fertilizers. The price of P and K fertilizers compared with the price and availability of poultry litter should be used to evaluate the economics/feasibility of using poultry litter or other manures and biosolids as a P and K source. When poultry litter is used as a P and K fertilizer, representative samples should be submitted to a qualified lab for analysis because poultry litter is not a homogeneous or consistent product; differences exist among houses, integrators and/or poultry type. On average, 1 ton of poultry litter contains 66 pounds P_2O_5 and 46 to 59 pounds K_2O, making it equivalent to 144 pounds of triple superphosphate (46% P_2O_5) and 77 to 98 pounds of muriate of potash (60% K_2O). The nutrient content of the litter usually decreases as moisture content increases since litter is analyzed on an "as is" or moist basis. Research shows that the P and K in poultry litter are plant available and should be applied at rates that supply the recommended P_2O_5 and K_2O rates. Fresh and pelleted forms

Figure 5-12. Winter wheat yield response to preplant-applied poultry litter as compared to late winter-applied urea.



apply the wheat crop's P and/or K requirement as poultry litter, which for Arkansas wheat fields that require P fertilization will be 1 to 2 tons per acre for litter having average P and K nutrient concentrations.

Biosolids can also provide N when fall applied to wheat. A limited amount of research has shown that 40 lb N per acre fall applied as biosolids performs as well as an equivalent rate of fall-applied urea N. As with poultry litter, the nutrient content and quality of the biosolid should be verified before purchase and application. Biosolids may contain greater concentrations of N and P than poultry litter but may also contain little or no K.

of poultry litter behave similarly with regard to the plant availability of N, P and K.

The N content of poultry litter varies considerably but, on average, contains 41 to 71 pounds N per ton depending on the type of production. Preplant-incorporated biosolids and manures can supply some N to the wheat crop. The mineralization or release of plant-available N contained in poultry litter occurs relatively quickly (e.g., within 3 to 4 weeks) in warm soils. Arkansas research shows that preplant-applied poultry litter can provide some plant-available N to winter wheat, but per unit of applied N, it is less efficient than urea N (Figure 5-12). The time of poultry litter application to winter wheat has little to no effect on wheat yield with wheat yields being equal across application times ranging from preplant to early March. The contribution of plant-available N from low to moderate rates (<120 lb total poultry litter N/acre) of poultry litter is relatively small. Overall, estimates from Arkansas research suggest that about 30%-35% of the total N in poultry litter will contribute toward the wheat N rate requirement. For example, if 1.5 tons of poultry litter that contains 3.0% total N is applied, it contributes 90 lb total N/acre, of which only about 29 lb N/acre would count toward the season total N rate. It should also be noted that the N contribution of poultry litter toward the wheat crop's N requirement has been quite variable in research trials and almost unnoticeable when very low rates (<1 ton litter per acre) are applied. For these reasons, a sound approach for utilizing poultry litter in wheat fertilization programs is to

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